



US007785562B1

(12) **United States Patent**
Bossard

(10) **Patent No.:** **US 7,785,562 B1**
(45) **Date of Patent:** **Aug. 31, 2010**

(54) **SYSTEM AND METHOD FOR SEPARATING HYDROGEN GAS FROM A HYDROCARBON USING A HYDROGEN SEPARATOR ASSISTED BY A STEAM SWEEP**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 285 days.

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(21) Appl. No.: **11/879,235**

(57) **ABSTRACT**

(22) Filed: **Jul. 18, 2007**

(51) **Int. Cl.**
C01B 3/26 (2006.01)
C01B 3/02 (2006.01)
C01B 3/24 (2006.01)

A power generation system and a fuel processor for use therein. The system produces steam from a water supply. A highly heated reaction chamber is provided. A common hydrocarbon fuel is mixed with water and introduced into the heated reaction chamber. The hydrocarbon fuel and water react at pressure and temperature, producing less complex gases. The resultant gases are passed into a hydrogen separator that is directly swept with steam. The hydrogen separator separates hydrogen from the resultant gases. The separated hydrogen is carried away from the hydrogen separator by the steam, thereby making the hydrogen separator more efficient. The hydrogen is separated from the steam is used to power a fuel cell. The fuel cell produces electricity and water is recycled back into the system.

(52) **U.S. Cl.** **423/652**; 423/648.1; 423/650; 423/651

(58) **Field of Classification Search** 423/648.1, 423/650–656

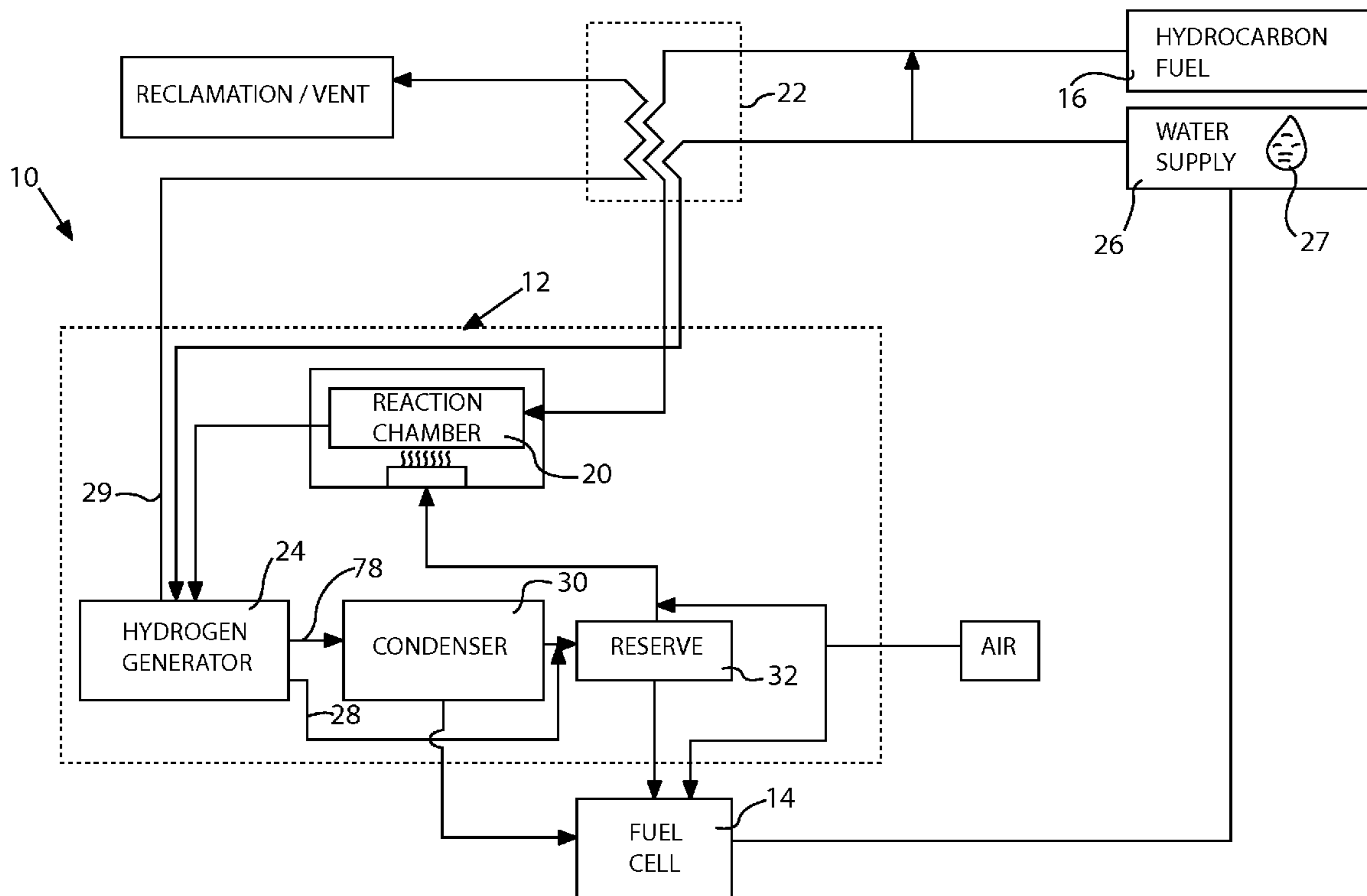
See application file for complete search history.

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9 Claims, 4 Drawing Sheets



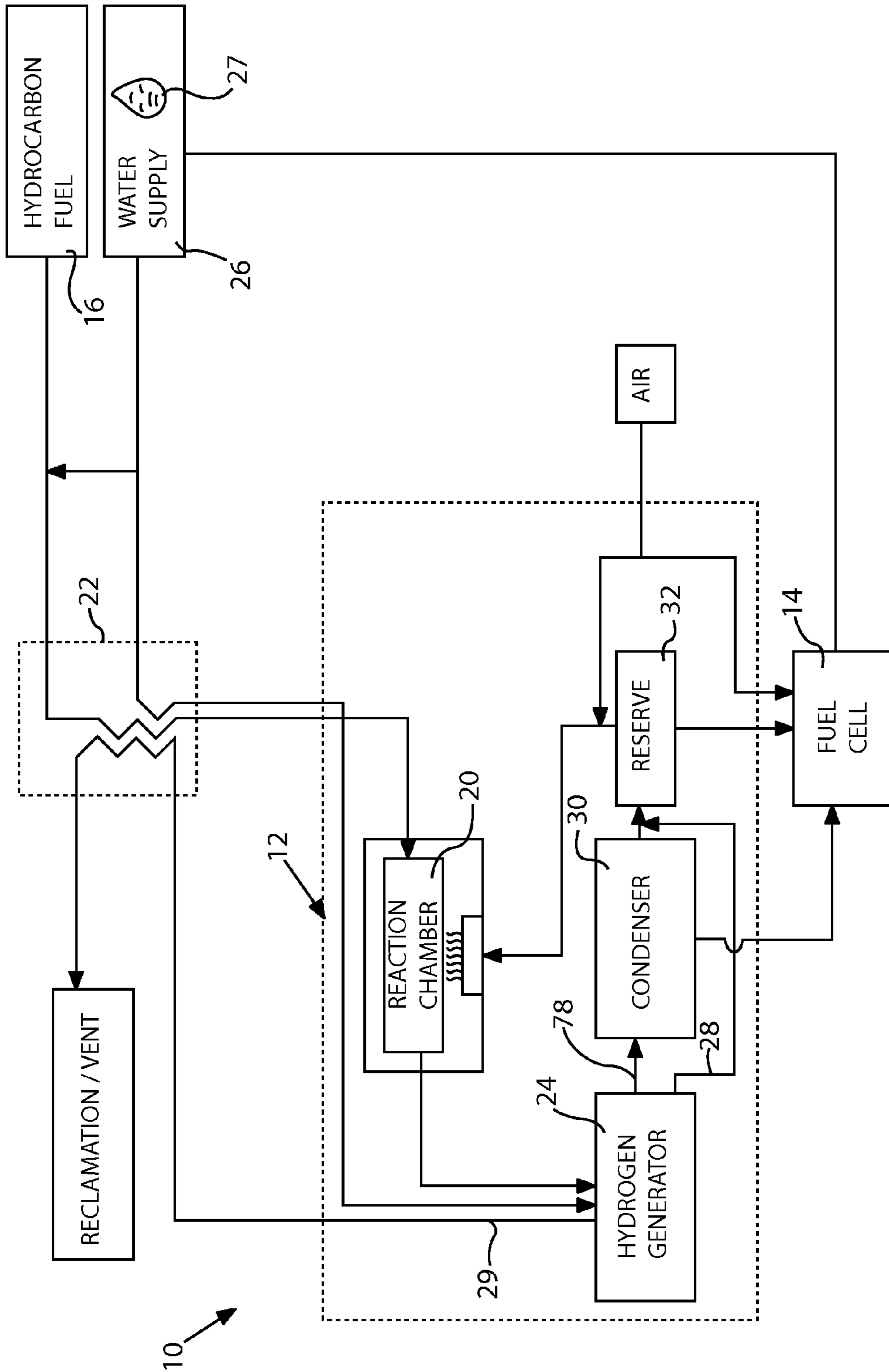


FIG. 1

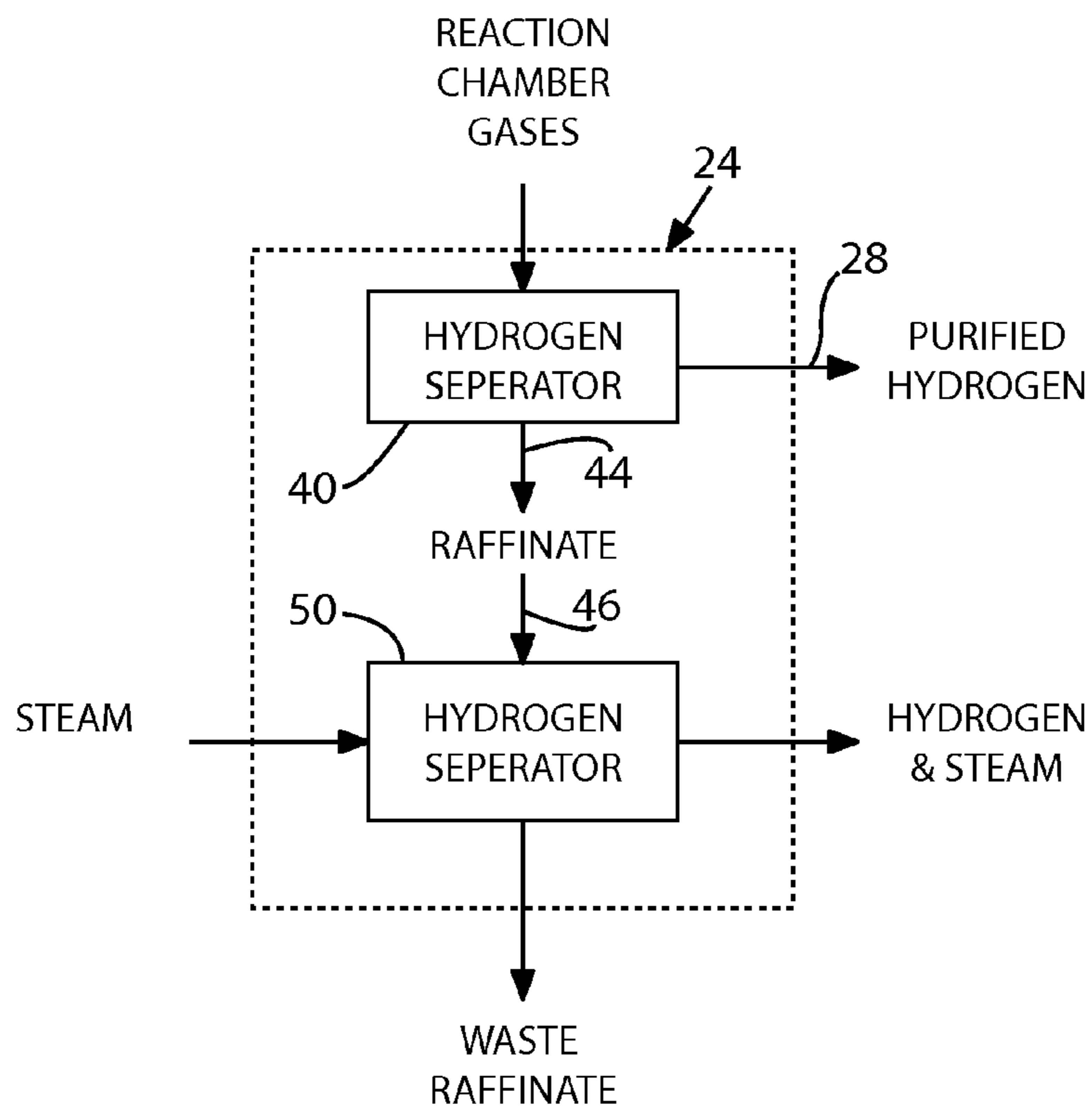


FIG. 2

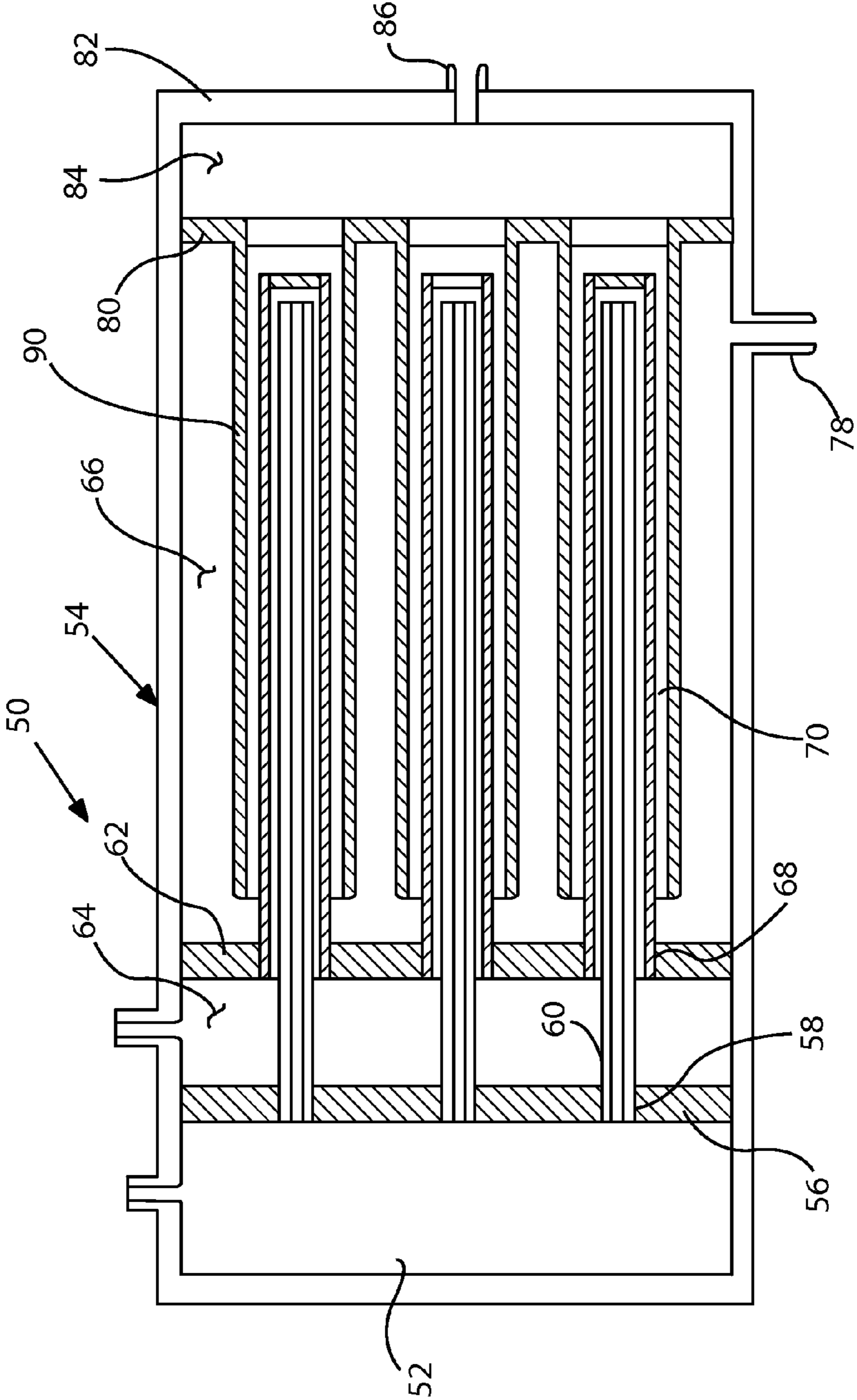


FIG. 3

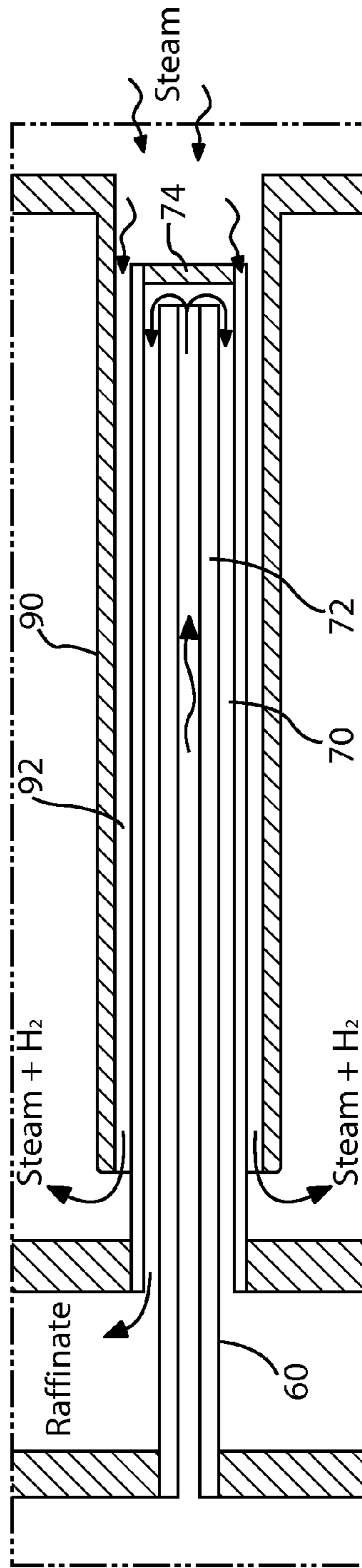


FIG.4

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**SYSTEM AND METHOD FOR SEPARATING
HYDROGEN GAS FROM A HYDROCARBON
USING A HYDROGEN SEPARATOR
ASSISTED BY A STEAM SWEEP**

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to systems and methods that are used to separate molecular hydrogen from a volume of gas. More particularly, the present invention is related to systems and methods that separate hydrogen from a volume of mixed gas and utilize the hydrogen as fuel for a fuel cell.

2. Prior Art Description

In industry, there are many applications for the use of ultra pure molecular hydrogen. For instance, there are many fuel cells that operate using hydrogen. The hydrogen, however, must be ultra pure. Any molecules of carbon dioxide, carbon monoxide or other contaminant gases that are received by the fuel cell cause damage to the fuel cell and decrease both the efficiency and the functional life of the fuel cell.

Commonly, purified hydrogen for use by a fuel cell is generated using a two stage process. In the first stage, hydrogen gas is separated from a source gas. For example, hydrogen can be separated from a hydrocarbon gas. However, in many common processes that produce hydrogen, the hydrogen gas produced is not pure. Rather, when hydrogen is produced, the resultant gas is often contaminated with hydrocarbons and/or other contaminants. It is for this reason that a second processing stage is used.

In the second processing stage, the separated hydrogen gas is then purified to remove lingering contaminants. In the art, ultra pure hydrogen is commonly considered to be hydrogen having purity levels of at least 99.9999%. In the prior art, one of the most common ways to purify contaminated hydrogen gas is to pass the gas through a conduit made of a hydrogen permeable material, such as palladium or a palladium alloy. As the contaminated hydrogen gas passes through the conduit, atomic hydrogen permeates through the walls of the conduit, thereby separating from the contaminants. In such prior art processes, the conduit is kept internally pressurized and is typically heated to at least three hundred degrees centigrade. Within the conduit, molecular hydrogen disassociates into atomic hydrogen on the surface of the conduit and the conduit absorbs the atomic hydrogen. The atomic hydrogen permeates through the conduit from a high pressure side of the conduit to a low pressure side of the conduit. Once at the low pressure side of the conduit, the atomic hydrogen recombines to form molecular hydrogen. The molecular hydrogen that passes through the walls of the conduit can then be collected for use. Such prior art systems are exemplified by U.S. Pat. No. 5,614,001 to Kosaka et al., entitled Hydrogen Separator, Hydrogen Separating Apparatus And Method For Manufacturing Hydrogen Separator.

In the past, fuel cells have mostly been used to power exotic devices, such as spacecraft. Accordingly, the cost of operating a two stage system for obtaining purified hydrogen is of little concern. However, if fuel cells are to be used to power more traditional devices, such as automobiles, a two stage process for obtaining purified hydrogen is highly problematic. Consider an automobile. Using a two stage system, hydrogen gas would be separated from a source gas at some processing plant. The hydrogen gas would then be shipped under pressure to gas stations for storage. The high pressure hydrogen gas would then have to be pumped into the automobile for use by a fuel cell. This fueling scenario requires pressurized tanks to be maintained both at the gas station and within the automobile. It also requires pumping lines and couplings for fueling the automobile that can hold hydrogen gas under

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immense pressure. The dangers and cost of refueling alone have long been deterrents to producing any vehicle that runs on hydrogen.

A long-standing need, therefore, exists for a single stage fuel processing system, wherein a traditional fuel, such as diesel, gasoline, can be pumped into the gas tank of an automobile or a ship in the ordinary manner. A fuel processing system carried within the automobile or ship will then obtain ultra pure hydrogen from traditional fuel in a single stage process that operates on an as-needed basis. The ultra pure hydrogen can then be used to power a fuel cell for the energy efficient production of electrical power.

This need is met by the present invention as described and claimed below.

SUMMARY OF THE INVENTION

The present invention is a power generation system and a micro-channel fuel processor for use within a power generation system. A highly heated reaction chamber is provided. A common hydrocarbon fuel is mixed with water and is introduced into the heated reaction chamber. The hydrocarbon fuel and water react, producing less complex resultant gases. The resultant gases are passed into a micro-channel hydrogen separator that is directly swept with a flow of steam. The hydrogen separator separates hydrogen from the resultant gases. The separated hydrogen is carried away from the hydrogen separator by the steam, thereby making the hydrogen separator more efficient. The hydrogen is separated from the steam and is used to power a fuel cell. The fuel cell produces electricity and water that can be recycled back into the system.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention, reference is made to the following description of an exemplary embodiment thereof, considered in conjunction with the accompanying drawings, in which:

FIG. 1 is a schematic of an exemplary embodiment of a power generating system containing a fuel processor in accordance with the present invention;

FIG. 2 is a schematic of a hydrogen generator used within the power generating system;

FIG. 3 is a cross-sectional view of an exemplary hydrogen separator that can be used within the hydrogen generator; and

FIG. 4 is an enlarged view of a section of a portion of the hydrogen separator shown in FIG. 3.

DETAILED DESCRIPTION OF THE DRAWINGS

The present invention fuel processing system provides a highly efficient means for converting a hydrocarbon fuel, at ambient pressure, directly into ultra-pure hydrogen. The ultra-pure hydrogen is then used to power a fuel cell for the production of electricity.

Referring to FIG. 1, there is shown a schematic of an exemplary embodiment of a power generation system **10** that contains a fuel processor **12** and a fuel cell **14**. The fuel processor **12** converts a hydrocarbon fuel **16** into ultra-pure hydrogen that is then used to run the fuel cell **14**.

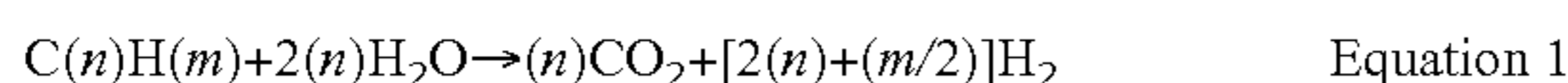
The fuel cell **14** receives ultra-pure hydrogen from the fuel processor **12** and produces electricity. There are several prior art fuel cell designs that require ultra-pure hydrogen for proper operation. Any such fuel cell can be adapted for used as part of the overall power generation system **10**.

The fuel processor **12** includes a reaction chamber **20**, a heat exchanger **22** and a hydrogen generator **24**. A traditional hydrocarbon fuel **16** is provided to the fuel processor **12**. The hydrocarbon fuel **16** can be either in liquid or gas form. The

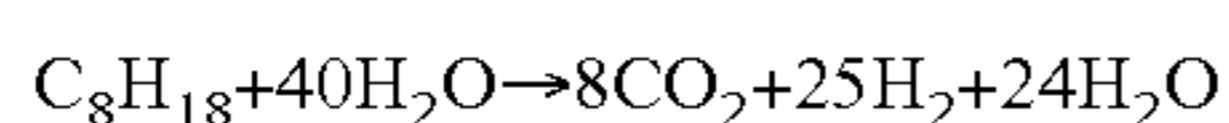
hydrocarbon fuel **16** contains some type of primary hydrocarbon that is mixed with water and then vaporized. The hydrocarbon contained within the hydrocarbon fuel **16** is represented by the formulation $C(n)H(m)$ where (n) is the number of carbon atoms in the hydrocarbon and (m) is the number of hydrogen atoms in the hydrocarbon. Appropriate fuels would include, but are not limited to, diesel fuel, gasoline, kerosene, natural gas, propane and alcohols.

A water supply **26** is provided. The water supply **26** has a split feed. Some water **27** from the water supply **26** is mixed with the hydrocarbon fuel **16** in precalculated amounts governed by Equation 1 provided below. Some of the water **27** from the water supply **26** is fed through the heat exchanger **22** that converts the water **27** to steam. The heat exchanger **22** can therefore be considered a steam generator that is disposed along the water line. The water **27** in the water supply **26** is replenished by the power generation system **10** as will later be explained.

If the hydrocarbon fuel **16** selected is a liquid, the hydrocarbon fuel **16** and water **27** are mixed as liquids. The fuel/water combination passes through the heat exchanger **22**, therein both the hydrocarbon fuel **16** and the water **27** are converted into vapor. The vaporized hydrocarbon fuel **16** and steam are fed into a heated reaction chamber **20**. The hydrocarbon fuel **16** and steam are received in controlled amounts. The reaction chamber **20** is maintained at a temperature between 550°C . and 800°C . depending of the particular fuel. At these temperatures, any complex hydrocarbons present in the hydrocarbon fuel **16** break apart into simpler molecules. The gas composition due to the mass balance is shown in Equation 1 below when the reaction is fully converted to carbon dioxide and hydrogen.



Using real numbers, assume the primary hydrocarbon in the hydrocarbon fuel **16** is C_8H_{18} , such as the case with diesel fuel. Using Equation 1, the following reaction occurs.



It can therefore be seen that by combining the hydrocarbon fuel **16** with steam in the reaction chamber **20**, a hydrocarbon containing only eighteen hydrogen atoms (H) results in reactant gases that include 25 free molecules of hydrogen gas (H_2). As shown in Equation 1, the water to carbon ration is 4 or more waters for each carbon atom in the hydrocarbon or alcohol to prevent coke (carbon deposits) from forming. In Equation 1 we have used 5 water molecules for each carbon atom in the hydrocarbon chain.

The reaction chamber **20** is coupled to a hydrogen generator **24**. An exemplary structure for the hydrogen generator **24** is later described.

The hydrogen generator **24** receives the reactant gases from the reaction chamber **20**. The reactant gases are the gases on the right hand side of Equation 1. The hydrogen generator **24** separates the hydrogen from the reactant gases. The hydrogen generator **24** has three outputs. One output **28** is for the purified hydrogen gas. A second output **78** is for purified hydrogen gas mixed with steam. A third output **29** is for raffinate gases.

The hydrogen gas and steam that exit the second output **78** are fed into a condenser **30**. The steam condenses in the condenser **30**, therein enabling the purified hydrogen gas to separate from the steam after the steam condenses to water. The water from the condensed steam is recycled and the latent heat of vaporization is transferred to the incoming fuel and water and mix and sweep water. The most of the purified hydrogen gas containing a small amount of water vapor after the water condenser is fed to the fuel cell **14**.

The raffinate gas output **29** of the hydrogen generator **24** primarily passes CO_2 and steam. Gases exiting through the raffinate gas output **29** are hot but below the boiling point of water at the pressure and temperature of the raffinate gas stream. The raffinate gas output **29** is therefore fed into the heat exchanger **22** so that some of the heat in the exiting gases can be utilized to heat the incoming fuel and water mix and the other gas be feed into the fuel processor.

The ultra-pure hydrogen from the hydrogen generator **24** is fed to the fuel cell **14**. The fuel cell **14** receives the ultra-pure hydrogen and oxygen from ambient air. The fuel cell **14** converts the ultra-pure hydrogen and air into electricity and water (H_2O). Depending upon the type of fuel being used, the volume of water created by the fuel cell **14** when add to the water recovered from the raffinate and the water recovered from the steam sweep can exceed the volume of water **27** that is fed into the reaction chamber **20**. Thus, the water produced by the fuel cell **14** can be used to replenish the water supply **26** and still excess clean water exists for use in other purposes.

The reaction chamber **20** can be heated in many ways. For instance, electrical power from the fuel cell **14** can be used to heat the reaction chamber **20**. However, one of the most efficient ways to heat the reaction chamber **20** is to burn some of the purified hydrogen produced by the hydrogen generator **24**. The purified hydrogen flowing out of the reaction chamber **20** to the fuel cell **14** can be tapped. A small percentage of that hydrogen gas can be mixed with air to heat the reaction chamber **20**. A reactant **31**, such as palladium, can be present in the reaction chamber **20** to start a rapid oxidation reaction between the hydrogen and the air. As the hydrogen burns, it rapidly heats the reaction chamber **20** to its operational temperature.

A small supply reserve **32** of ultra-pure hydrogen can be optionally maintained so that there is enough hydrogen gas present to initially heat the reaction chamber **20** upon start up.

The combustion of the hydrogen gas in the steam generator **22** with air results in water vapor and nitrogen (N_2) rich air mixture because O_2 has been removed during the combustion of hydrogen. The water vapor can be recovered and recycled to the water supply **26**. The trace gases can be vented to the surrounding atmosphere.

In FIG. 2, a schematic of an exemplary hydrogen generator **24** is shown. Referring to FIG. 2 in conjunction with FIG. 1, it can be seen that the hydrogen generator **24** receives the mixed gases from the reaction chamber **20**. The mixed gases are the gases represented on the right side of Equation 1. Within the hydrogen generator **24**, the mixed gases are fed into a traditional hydrogen separator **40**. There are many hydrogen separators that exist in the prior art that separate hydrogen gas from a mixed gas by exposing the mixed gas to a hydrogen permeable membrane. Any such prior art hydrogen separator can be used. However, it is preferred that a highly efficient micro-channel hydrogen separator be used. Highly efficient hydrogen separators are the subjects of the following co-pending patent applications by the present applicant: U.S. patent application Ser. No. 11/522,004, entitled System And Method For Separating Hydrogen Gas From A Mixed Gas Source Using Composite Structure Tubes, filed Sep. 18, 2006; U.S. patent application Ser. No. 11/341,541, entitled System And Method For Processing Fuel For Use By A Fuel Cell Using A Micro-channel Catalytic Hydrogen Separator, filed Jan. 27, 2006; U.S. patent application Ser. No. 11/522,004, entitled System And Method For Separating Hydrogen Gas From A Mixed Gas Source Using Composite Structure Tubes, filed Sep. 18, 2006; and U.S. patent application Ser. No. 11/515,976, entitled Composite Structure For High Efficiency Hydrogen Separation Containing Preformed Nano-particles In A Bonded Layer, filed Sep. 3, 2006. The disclosures of all of these applications are incorporated into this specification by reference.

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The traditional hydrogen separator **40** separates most of the hydrogen gas from the mixed gas. As is indicated by output **28** in FIG. 1, the purified hydrogen gas is fed to the fuel cell **14**, through the reserve **32**. However, the raffinate output **44** of the traditional hydrogen separator **40** is fed into the input **46** of a steam swept hydrogen separator **50**.

The steam swept hydrogen separator **50** essentially uses a traditional hydrogen separator unit. However, purified hydrogen is actively swept out of the hydrogen separator by a flow of steam. As has been previously mentioned, a hydrogen separator contains a hydrogen permeable membrane. The hydrogen permeable membrane has a first side that is exposed to the mixed gas and a second side that is exposed only to the purified hydrogen. Hydrogen gas from the mixed gas dissociates and passes through the hydrogen permeable membrane as atomic hydrogen. Once through the hydrogen permeable membrane the atomic hydrogen reassociates into molecular hydrogen. The efficiency by which hydrogen passes through a hydrogen permeable membrane depends upon many factors. One of these factors is the concentration of hydrogen molecules on the purified side of the membrane. By providing a flow of steam across the purified side of the hydrogen permeable membrane, hydrogen molecules are swept away. The decrease in hydrogen molecules on the purified side allows for the more efficient permeation of hydrogen from the mixed gas side. The result is a highly efficient transfer of hydrogen from the mixed gas through the hydrogen permeable membrane.

Referring to FIG. 3, an exemplary structure of the steam swept hydrogen separator **50** is shown. The steam swept hydrogen separator **50** has an enclosed housing **54**. A plenum chamber **52** is disposed at one end of the enclosed housing **54**. The enclosed housing **54** is preferably made of stainless steel or another high strength alloy that is non-reactive to any of the component gases received from the reaction chamber.

The plenum chamber **52** is defined between the interior of the enclosed housing **54** and a first chamber wall **56**. The first chamber wall **56** contains a plurality of holes **58** that are symmetrically arranged in a highly space efficient manner. The holes **58** are preferably spaced as densely as possible while still maintaining a predetermined minimum area of material around each of the holes **58**.

A plurality of support tubes **60** extend from the first chamber wall **56**. The support tubes **60** have solid walls with opposing open ends. The support tubes **60** are joined to the first chamber wall **56** at each of the holes **58**. In this manner, the holes **58** directly communicate with the interior of the support tubes **60** and any gas flowing out of the plenum chamber **52** through the first chamber wall **56** must flow through the support tubes **60**.

Although the exemplary embodiment shows only three support tubes **60** that communicate with the plenum chamber **52**, it will be understood that hundreds may be present. The use of three is for simplicity of illustration.

The support tubes **60** have a length nearly as long as the interior of the enclosed housing **54**. The support tubes **60** and the first chamber wall **56** are preferably made of the same non-reactive material as is the enclosed housing **54**. In this manner, the first chamber wall **56**, and the support tubes **60** have the same coefficient of thermal expansion as does the enclosed housing **54**.

A second chamber wall **62** is disposed within the enclosed housing **54** at a point adjacent the first chamber wall **56**. The second chamber wall **62** creates two additional chambers within the enclosed housing **54** in addition to the plenum chamber **52**. A raffinate gas collection chamber **64** is created between the first chamber wall **56** and the second chamber wall **62**. Furthermore, a steam swept hydrogen collection chamber **66** is created between the second chamber wall **62** and a third chamber wall. A collection port **78** communicates

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with the steam swept hydrogen collection chamber **66** so that gases can be drawn out of the steam swept hydrogen collection chamber **66**.

The second chamber wall **62** defines a plurality of holes **68** that are slightly larger than the diameter of the support tubes **60** that are extending from the first chamber wall **56**. The holes **68** in the second chamber wall **62** are aligned with the support tubes **60**, thereby allowing the support tubes **60** to extend through the second chamber wall **62**.

A plurality of hydrogen permeable tubes **70** are coupled to the second chamber wall **62**. The hydrogen permeable tubes **70** are aligned with the holes **68** in the second chamber wall **62** and pass around the support tubes **60**. It will therefore be understood that the hydrogen permeable tubes **70** are coaxially aligned with the support tubes **60** and surround the support tubes **60**. The hydrogen permeable tubes **70** are preferably palladium or a palladium based alloy, such as a palladium/silver alloy. However, other hydrogen permeable alloys can also be used.

The third chamber wall **80** is disposed near the distal end wall **82** of the enclosed housing **54**. The third chamber wall **80** creates a steam supply chamber **84** between the third chamber wall **80** and the distal end wall **82**. Steam is supplied to the steam supply chamber **84** through a steam inlet port **86** that receives steam from the heat exchanger **25** (FIG. 1). A plurality of steam supply tubes **90** extends from the third chamber wall **80** into the steam swept hydrogen collection chamber **66**. The steam supply tubes **90** communicate with the steam supply chamber **84**. As such, it will be understood that any steam that is fed into the steam supply chamber **84** will flow out of the steam supply chamber **84** through the steam supply tubes **90**.

The steam supply tubes **90** are all coaxially aligned with the hydrogen permeable tubes **70** in the steam swept hydrogen collection chamber **66**. The steam supply tubes **90** have an internal diameter that is larger than the external diameter of the hydrogen permeable tubes **70**. Accordingly, the hydrogen permeable tubes **70** can pass inside the steam supply tubes **90** and only a small gap separates the interior of the steam supply tubes **90** with the exterior of the hydrogen permeable tubes **70**.

Referring to FIG. 4, it can be seen that a first gap space **72** exists between the outside surface of the support tubes **60** and the inside surface of the hydrogen permeable tubes **70**. The size of the first gap space **72** is dependent upon the thickness of the walls of the hydrogen permeable tubes **70**. Preferably, the size of the gap space **72** is between two times (2×) and fifty times (50×) the thickness of the wall that forms the hydrogen permeable tubes **70**. The first gap space **72** runs along the length of the support tubes **60** in the area where the hydrogen permeable tubes **70** overlap the support tubes **60**.

The hydrogen permeable tubes **70** are longer than the support tubes **60** they surround. The free ends of the hydrogen permeable tubes **70** are closed. In the shown embodiment, an internal end cap **74** is internally brazed in place at the end of each of the hydrogen permeable tubes **70**. The end caps **74** are preferably brazed to the inside of the hydrogen permeable tubes **70**. In this manner, the end caps **74** do not restrict the hydrogen permeable tubes **70** from expanding outwardly when heated and saturated with molecular hydrogen.

The steam supply tubes **90** surround the hydrogen permeable tubes **70**. Accordingly, a second gap space **92** exists between the exterior of each hydrogen permeable tube **70** and the interior of each steam supply tube **90**. The second gap space **92** is at least as large as the first gap space **72** and can be as 0.5 millimeters.

Referring to FIG. 3 and FIG. 4, it will be understood that in operation, the enclosed housing **54** and all its contents are heated to an operating temperature in excess of 300 degrees Centigrade by the incoming gases from the reaction chamber.

The gases from the reaction chamber are introduced into the plenum chamber 52. The gases fill the plenum chamber 52 and flow into the support tubes 60 through the first chamber wall 56. The gases exit the far ends of the support tubes 60 and are forced to flow through the gap spaces 72 that exist between the exterior of the support tubes 60 and the interior of the surrounding hydrogen permeable tubes 70. The gap spaces 72 drain into the raffinate gas collection chamber 64. However, as the gases flow through the gap spaces 72, the flowing gases spread thinly over the outside surfaces of the hydrogen permeable tubes 70. The length and width of the gap spaces 72, as well as the gas flow rate, are engineered to maximize the efficiency at which the hydrogen gas permeates through the hydrogen permeable tubes 70. By spreading the contaminated gas thinly over the surfaces of the hydrogen permeable tubes 70, the hydrogen contained within the reaction chamber gases does not have to diffuse far before it contacts hydrogen permeable material. In this manner, a high percentage of the hydrogen available in the reaction chamber gases are provided with the opportunity to disassociate from the reaction chamber gases and pass through the hydrogen permeable tubes 70.

As hydrogen gas passes through the hydrogen permeable tubes 70, the hydrogen gas enters into the second gap space 92 that exists between the hydrogen permeable tubes 70 and the steam supply tubes 90. Steam is fed into the steam supply chamber 84. The steam flows out of the steam supply chamber 84 through the steam supply tubes 90. Accordingly, the steam is forced to flow through the second gap space 92 that exists between the hydrogen permeable tubes 70 and the steam supply tubes 90. As the steam flows through the second gap spaces 92, the steam sweeps hydrogen gas out of the second gap spaces 92. The combined steam and hydrogen gas then leave the steam swept hydrogen collection chamber 66 through the outlet 78. The combined hydrogen gas and steam is then fed to the condenser 30 (FIG. 1) for separation. After separation, the hydrogen gas is pure, being contaminated only with water vapor. Such an output is ideal for use by a proton exchange membrane fuel cell.

As the hydrogen gas is swept away from the exterior of the hydrogen permeable tubes 70, the partial pressure of hydrogen outside the hydrogen permeable tubes decreases. This increases the efficiency at which hydrogen gas passes through the hydrogen permeable tubes 70.

The non-hydrogen components of the reaction chamber gases flow through the gap spaces 72 and into the raffinate gas collection chamber 64. The raffinate gas is then drawn out and vented.

Since the gases from the reaction chamber pass through the plenum chamber 52 and the gap spaces 72 within the steam swept hydrogen separator 50, it should be understood that catalytic material can be placed in these areas. The catalytic material can be used to further crack lingering hydrocarbons, there by releasing more hydrogen gas.

In the embodiment of the hydrogen generator 24 illustrated in FIG. 2, the hydrogen generator 24 contains two hydrogen separators 40, 50. The first hydrogen separator 40 is traditional, the second is steam swept. It should be understood that the use of the first traditional hydrogen separator 40 is exemplary. The invention works well with just a single steam swept hydrogen separator. Likewise, two or more steam swept hydrogen separators can be used in series.

It will further be understood that the illustrated embodiment of the overall fuel processor is merely exemplary and that a person skilled in the art can make many changes using functionally equivalent configurations. For example, the reaction chamber and the combustion compartment that heats the reaction chamber can have numerous configurations. Furthermore, the structure of the heat exchanger and the fuel cell

are a matter of design selection. It will be further understood that an embodiment of the present invention can be made where a plurality of fuel processors and/or fuel cells are used together. All such variations, modifications and alternate embodiments are intended to be included within the present invention as defined by the claims.

What is claimed is:

1. A method of producing hydrogen gas, comprising the steps of:

- providing a hydrocarbon fuel;
- providing water;
- mixing said hydrocarbon fuel with some of said water and heating both until said hydrocarbon fuel and said water react to produce reactant gases;
- removing some hydrogen gas from said reactant gases, therein producing raffinate gases;
- providing a hydrogen separator containing a hydrogen permeable surface with a first side and a second side;
- producing steam from said water;
- exposing said first side of said hydrogen permeable surface to said raffinate gases, wherein hydrogen from said reactant gases passes through said hydrogen permeable surface to said second side; and
- flowing some of said steam across said second side, therein sweeping hydrogen away from said hydrogen permeable surface.

2. The method according to claim 1, further including the step of separating hydrogen gas swept away with steam from said steam by condensing said steam.

3. A method of generating power, comprising the steps of:

- providing a fuel cell that operates using hydrogen gas;
- providing a hydrocarbon fuel;
- providing water;
- reacting said hydrocarbon fuel with some of said water in a heated environment to produce reactant gases;
- removing some hydrogen gas from said reactant gases, therein producing raffinate gases;
- producing steam with some of said water;
- providing a hydrogen separator;
- passing said raffinate gases through said hydrogen separator to obtain hydrogen gas;
- sweeping said hydrogen gas from said hydrogen separator with some of said steam; and
- supplying said hydrogen gas to said fuel cell, wherein said fuel cell produces power.

4. The method according to claim 3, wherein said fuel cell generates water when producing said power, and wherein said water is recycled for use in reacting with said hydrocarbon fuel.

5. The method according to claim 3, further including the step of removing water from said reactant gases.

6. The method according to claim 3, further including heating said heated environment by burning some of said hydrogen gas.

7. The method according to claim 3, further including producing said steam by passing some of said water through a heat exchanger.

8. The method according to claim 3, further including the step of heating said heated environment to a temperature in excess of 550° C.

9. The method according to claim 3, wherein said step of providing a hydrocarbon fuel includes providing a hydrocarbon fuel selected from a group consisting of diesel fuel, gasoline, kerosene, propane, natural gas and alcohols.